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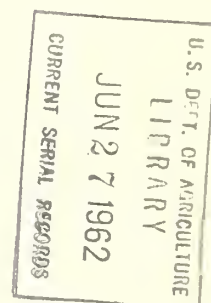
EVALUATION OF FOREST FIRE RETARDANTS --- A TEST OF CHEMICALS ON LABORATORY FIRES



BY

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EVALUATION OF FOREST FIRE RETARDANTS--
A TEST OF CHEMICALS ON LABORATORY FIRES

PURPOSE

The purpose of the research program reported here is to evaluate the ability of selected chemical fire retardants to slow down or stop the advance of a fire in forest fuels. Many factors enter into final selection of chemical fire retardants including effectiveness in various fuel and fire situations; aerial application characteristics; problems of corrosion, abrasion, and toxicity; cost; and ease of mixing, pumping, and storing. The tests covered in this report are concerned only with the relative effectiveness of seven different chemicals in slowing or stopping fire advance when each chemical is applied on a forest fuel in the same amount and manner. The fuel bed itself does not duplicate any specific natural fuel. It is merely an easily reproducible medium upon which various chemicals can be applied and the relative rates of fire spread compared.

THE PROGRAM IN BRIEF

Facilities of the Northern Forest Fire Laboratory were used in conducting the first controlled atmosphere tests of the relative fire retardant effectiveness of several chemicals. Seven of the chemicals that had been proposed to the U.S. Forest Service as being effective fire retardants suitable for aerial delivery had already passed certain previous laboratory and field tests and were considered appropriate for further testing under uniform controlled conditions. The chemicals tested were: algin-diammonium phosphate (algin-DAP), algin-calcium chloride (algin-gel), bentonite, sodium calcium borate (Firebrake), sodium calcium borate (Borate XPI-113--a new, experimental formula), ammonium sulphate-attapulgitic clay (Fire-Trol), and pectin-diammonium phosphate (pectin-DAP).^{1/}

Some chemicals were thought to be more effective within a shorter period of time after application than others, but others were considered to be more effective after longer intervals. The speed and duration of wind is known to affect rate of fire spread and perhaps also to affect the relative retardant abilities of the various chemicals. Perhaps a change of wind velocity might transpose the relative effectiveness of two or more chemicals. To test these parameters, the following variables were established:

^{1/} In reporting experimental work it is sometimes desirable to mention trade or brand names in the interest of brevity and clarity. Such mention does not imply endorsement of the products mentioned, nor does it imply non-endorsement of unnamed products.

7 chemicals
2 periods of drying after chemical application--1 hour and 3 hours
2 wind conditions: 0 m.p.h. and 3 m.p.h.
1 repetition of each of the above parameters
56 fires plus reruns, or possibly 75 fires in all

The three measurements of retarding ability of each chemical and the methods of measurement were:

1. Rate of fire spread, measured visually in the combustion laboratory and by thermocouples in the wind tunnel.
2. Radiation, measured by a radiometer in both the combustion laboratory and wind tunnel.
3. Convection column temperature, measured by thermocouples in both the combustion laboratory and wind tunnel.

Analysis of the data recorded from test fires was made on the basis of percentage reduction of the rate of spread, radiation, and convection column temperatures from the magnitude registered on similar untreated fuel-bed sections. The results are shown in figures 14, 15, and 16, and in table 2.

DEVELOPMENT OF CHEMICAL FIRE RETARDANTS

Chemical fire retardants and their systematic investigation are not new to foresters. The U.S. Forest Service began testing chemical additives for forest fire control in 1931 (Barrett, 1931). A paper titled "Chemical Methods of Combating Forest Fires" (Serebrennikov, 1934) reported on Russian studies in forest fire control during 1932 and 1933. Many of these early studies showed a very decided advantage for chemicals over plain water. For example, in experiments conducted in northern California 10-percent solutions of mono-ammonium phosphate extinguished from 50 to 80 percent more fire than an equal quantity of plain water (Truax, 1939). Experiments in Montana evaluated the possibility of bombing forest fires with water and chemicals (Barrows and Keilman, 1947).

Despite these apparent successes, chemicals were little used for forest fire control until 1955, when several factors combined to start the air tanker program. Chief among these factors were the interest of a group of northern California pilots skilled in agricultural aviation, the availability of surplus military aircraft with the power and maneuverability needed to fly in mountainous terrain, the development of sodium calcium borate, and the concept of applying the chemical as a retardant rather than as a suppressant.^{2/} The

^{2/} A retardant is used to treat the fuels at or ahead of the flame front so that the combustion process is modified when fire reaches the treated fuel, while a suppressant is used to cool or extinguish the flaming or glowing phases of combustion by direct application to the burning fuel (Wilson, 1960).

retardant concept allowed the pilot to fly outside of the smoke and flame to apply the chemical to unburned vegetation just ahead of the fire.

In 1961, 6 years after the start of the air tanker program, almost 6 million gallons of retardant--mostly Firebrake and bentonite--were cascaded on forest fires in national forests alone.

Many tank trucks are now equipped to use fire-fighting chemicals, and fire agencies are planning a large investment in additional similar equipment (Davis, Dibble, and Phillips, 1961). Both bentonite and Firebrake have proved to be useful as fire retardants. They have constituted by far the largest percentage of retardant material used. However, both materials have serious limitations: bentonite depends almost entirely on its water-retaining ability for effectiveness; Firebrake is effective much longer after application, but is toxic to vegetation and is relatively expensive. As a result, most air drops, particularly of bentonite, are being made as close as possible to the fire line rather than at predetermined locations that might give a tactical advantage.

FIRE RETARDANT EVALUATION SYSTEM

The U.S. Forest Service and several cooperating forest fire control agencies in the United States have established a standard system for evaluation and development of fire-fighting chemicals. This system consists of the following eight phases:

1. Performance requirements.--Describes the characteristics desired in fire retardants and fire suppressants and indicates to industrial producers the general types of chemicals needed. These specifications are prepared jointly by fire research groups and fire control agencies.
2. Initial screening of chemicals.--Normally performed by the chemical companies on chemicals which appear to meet the general requirements of phase 1. Some screening of other chemicals is done by fire research groups.
3. Laboratory tests of chemicals.--Determines which chemicals offer promise for further research and development. Tests will be similar to those outlined by Dibble, Richards, and Steck (1961). Experience to date shows that about 95 percent of the proposed chemicals are eliminated by this step.
4. Laboratory fire tests.--Evaluates the performance of chemicals on fires in forest fuels under standard conditions of fuel moisture, temperature, relative humidity, and wind speed. Chemical performance is tested at the Northern Forest Fire Laboratory, using the combustion laboratory, fuels lab, and wind tunnels. (This phase of retardant testing is reported in detail in this paper.)

5. Field tests.--Evaluates drop patterns, pumping and mixing requirements, application requirements in various fuel and vegetative types, and other operational problems. Tests are conducted jointly by the fire agencies and fire research groups using standardized procedures.
6. Operational tests.--Fire control personnel, pilots, and airport managers evaluate the performance of the mixing, handling, and effectiveness of the retardant on wild fires. Standard evaluation forms are used.
7. Engineering.--This phase deals with the design, development, testing, and evaluation of equipment required in handling, mixing, pumping, storage, and application of chemicals. Equipment-development groups study these problems in close cooperation with various equipment manufacturers. Fire research groups assist in providing required data on chemicals and their performance as fire retardants and suppressants.
8. Application guides.--The final phase consists of preparation of guides for storing, mixing, pumping, and application of various approved chemicals. These guides include information on when, where, and how to apply chemicals for both fire prevention and fire suppression. The guides are prepared jointly by fire research groups and the fire control agencies.

CHEMICALS

Recent Tests of Fire Retardants

Within the past 2 years the Pacific Southwest Forest and Range Experiment Station has screened more than 70 proposed fire-retardant chemicals and combinations of chemicals in accordance with phases 2 and 3 of the evaluation system shown above.

Several materials showing the most promise were field tested under phase 5 conditions before the standardized procedures were adopted. These tests included mixing and pumping trials by the Arcadia Equipment Development Center, and air drops and fire tests by the California Air Attack Coordinating Committee (CALAIRCO).^{3/}

^{3/} The California Air Attack Coordinating Committee represents the following five agencies: California Division of Forestry; Los Angeles County Fire Department; and Pacific Southwest Forest and Range Experiment Station, Region 5, and Arcadia Equipment Development Center of the U.S. Forest Service.

Firebrake and bentonite were also tested so that comparisons could be made between them and the new chemicals. The five new chemicals are briefly described below:

1. Algin-gel.--Algin-calcium chloride gel is produced by adding a small quantity of calcium chloride solution to water thickened with sodium alginate--a viscosity agent manufactured from the giant kelp.

Addition of the calcium chloride immediately forms a thick, water-holding gel that has been applied with good results from ground and air at several locations in the West. The gel initially holds large quantities of water but slowly dries to a tough, impervious film. Air drop tests of the gel show that as much as three times more material may reach the vegetation than from a similar drop of bentonite or the borates. An additional advantage is that very little material, other than water, is required; consequently, algin-gel requires little warehousing or handling and the gel is easily mixed by portable facilities. The viscosity and gel characteristics depend on the mix ratio of the algin and calcium chloride. The calcium chloride solution has been combined with algin water in several ways. Most commonly, the two solutions are pumped from separate tanks through a metering arrangement into a mixing chamber in the nozzle of the aircraft-loading device.

Algin-gel costs two or three times as much as bentonite, but at about 6 cents per gallon is still comparatively inexpensive. It is noncorrosive and nontoxic. The solution can spoil by bacterial or enzymatic action if stored for a few summer days without a preservative.

2. The diammonium phosphates.--In previous tests, diammonium phosphate (DAP) has consistently ranked near the top of most lists of forest fire retardants. Although used successfully in forest fire control in several parts of the United States, it has not proved entirely effective in plain water solutions under severe burning conditions and in heavy fuels in the West. Probably the chief reason is that the larger fuel surfaces retain insufficient chemical. However, recent tests with thickened DAP have been very promising (U.S. Forest Service, 1960).
 - a. Algin-diammonium phosphate.--DAP solutions, thickened with sodium alginate to about the consistency of motor oil, cling to vegetation in a thick layer. The chemicals can be mixed rapidly in batch-type mixing equipment. DAP is almost noncorrosive to mild steel, and corrosion of aluminum can be effectively controlled by an inhibitor. However, DAP corrodes copper, brass, and bronze under laboratory conditions if parts

are alternately exposed to the DAP solution and to oxygen. The cost of algin-DAP should be about 20 cents per gallon.

- b. Pectin-diammonium phosphate.--Ammonium pectate is a viscosity agent or thickener produced by the citrus industry. Although it forms a viscous solution with water, it quickly progresses to the consistency of mayonnaise when combined with diammonium phosphate. The resulting gel clings to vegetation; initially, it retains a large quantity of water, but later dries to a fire-retardant coating. In addition, pectin-DAP intumesces, or swells up, when heated and produces a valuable insulating layer.

Powdered pectin and DAP can be preblended and bagged together. The blend mixes readily in a batch-type mixer equipped with high-shear impellers. The cost of pectin-DAP should be 12 to 15 cents per gallon. Corrosive properties of pectin-DAP are similar to those of algin-DAP.

3. Fire-Trol.--This proprietary chemical is formulated and blended by the manufacturers. It is primarily a combination of ammonium sulphate and attapulgate clay. Ammonium sulphate, like DAP, is widely used as a fertilizer and ranks high as a fire retardant. Attapulgate clay is similar to bentonite in that it forms a stable gel-like slurry with water. Unlike bentonite, it is salt-tolerant and is compatible with such fire-retardant salt as ammonium sulphate. This substance initially retains a large quantity of water, and the 15-percent ammonium sulphate content remains an effective fire retardant when dry.

High-shear impellers are required to mix this material. Without an inhibitor, Fire-Trol corrodes copper, brass, and mild steel. The cost should be 12 to 15 cents per gallon.

4. Borate XPI-113.--This newly developed retardant is mixed at the rate of 1.5 pounds per gallon, compared to 4 pounds per gallon for Firebrake. The B_2O_3 content is about 10 to 12 percent, compared to about 30 percent in Firebrake. The two advantages (less bulk and greatly reduced toxicity) minimize two of the primary objections to the use of Firebrake. Borate XPI-113 mixes readily in equipment commonly used for Firebrake or bentonite. It is nontoxic to animals and noncorrosive to most metals used in fire-fighting equipment. Its cost should be 8 to 10 cents per gallon.

Letter Symbols for Chemical Names

Each chemical was assigned a code letter symbol to represent it during the burning tests at the Northern Forest Fire Laboratory. Two reasons prompted the assigning of letter symbols: (1) simplicity of identification and reference, and (2) an attempt to eliminate bias. The letters were drawn from a box in random fashion by the man in charge of mixing the chemicals. No identifying names were divulged until preliminary analysis of the data was completed. The letter symbols were:

A - Algin-gel
B - Bentonite
C - Pectin-DAP
D - Fire-Trol
E - Borate XPI-113
F - Firebrake
G - Algin-DAP

Mixing Chemicals

All chemicals were mixed by a uniform procedure. Three gallons of each retardant solution were prepared at the beginning of the program to eliminate need for remixing before the burning program was completed. All proportions were in accord with manufacturers' recommendations. A special high-shear impeller, developed by the Pacific Southwest Station, was driven by a heavy duty drill press at 2,000 r.p.m.

The proportions of chemicals to water were as follows (11,356.2 grams of water equals 3 gallons):

Table 1.--Chemical Mixing Data

Code	Common name	Material		Ratio to		Viscosity ^{1/}
		Water	Chemical	Water	Total Wt.	
		Grams	Grams	Percent	Percent	c.p.s.
A	Algin-gel	10,800	96	Keltex (FF1000	0.89	4,230
			6	CaCl ₂ ^{2/}	.06	
B	Bentonite	11,356.2	952.7	bentonite	8.39	4,600
C	Pectin-DAP	11,356.2	715.4	pectate (spp)	6.30	
			79.5	versene	.70	470
			1,703.4	diammonium phosphate	15.00	
D	Fire-Trol	11,356.2	3,810.1	Fire-Trol	33.55	490
E	Borate XPI-113	11,356.2	2,041.2	Borate XPI-113	17.97	923
F	Firebrake	11,356.2	5,443.1	Firebrake	48.93	450
G	Algin-DAP	11,356.2	170.3	Keltex (FF1000)	1.50	290
			1,703.4	diammonium phosphate ^{3/}	15.00	

^{1/} Data obtained with Brookfield viscometer, spindle 4, 60 r.p.m. and liquid temperature 74.5° F.

^{2/} 6 grams CaCl₂ is first added to 1,200 grams H₂O; then this mixture is added to the 9,600 grams of H₂O-Keltex solution.

^{3/} Added to Keltex solution.

Selection of Chemical for Each Fire

Selection of the chemical for each of the six fires to be burned daily was done on a random scheme. No repetition of any chemical and drying time was made on the same day.

Application of Chemical to Fuel Bed

Amount

Two criteria determined the amount of chemical to be applied to each fuel bed:

1. The amount should be sufficient to slow fires down, but not to the point where rates of spread become too erratic for reproducible measurements.
2. The amount should conform somewhat to the actual quantity measured on the ground from aerial drops.

An application rate of 2 gallons per 100 square feet satisfied both requirements (Davis, 1960; Storey, Wendel, and Altobellis, 1959). An equivalent amount for the area to be covered in the present experiments is 473 cc. One-third, or 158 cc., was applied to each of the three layers of the fuel bed.

Method

All chemicals were applied in the same manner. A Brown "Speedy" model paint spray gun, with an 0.072-inch diameter round-orifice nozzle, was used with 17 p.s.i. air pressure at the service outlet.

A large syringe was used to transfer 158 cc. of the retardant to the spray gun. The retardant was sprayed uniformly over a 1-inch thick layer of ponderosa pine needles. (Refer to FUELS section below for description of fuel bed.) The spray gun was held approximately 18 inches above the needles and a pattern was followed to assure even distribution of retardant on the needles. The needles in the first 4 feet of the fuel bed were shielded to prevent any mist from settling on them. Second and third layers of needles were added, and each layer was sprayed with 158 cc. of retardant. This system assured that needles on the bottom and middle of the fuel bed were treated similarly to those on top.

The method of application just described may or may not have given each chemical equal advantage in respect to the manner in which it settled on the fuel particles. Two chemicals, bentonite and algin-gel, had much higher viscosity than the other five (see table 1). Application of bentonite was relatively easy since its thixotropic nature permitted its momentary thinning during ejection from the spray gun. However, since algin-gel is not as thixotropic, some difficulty of application was experienced. Much has yet to be learned about the effect of application method on the possible change in characteristics of a chemical, both when applied on a small scale for

experimental purposes and when applied from aircraft or pumbers, on an operational basis. Without this specific knowledge, the method developed and described here appeared to give as uniform an application as is presently possible.

A



B



C



Figure 1.--Chemicals: A., Mixing; B., Filling syringe;
C., Spraying a fuel bed.

FUELS

The ideal fuel for use in evaluating fire retardants would represent the major fuel types that carry forest fires: grass, brush, leaves, and branch wood. This ideal fuel would receive chemicals in a manner similar to the way that natural fuels would receive aircraft-dropped chemicals; and, finally, this fuel should be one that could be exactly duplicated for many tests under uniform conditions.

No completely satisfactory fuel complex for use in studies of fire retardants has yet been developed. However, the fire physics research project at the Northern Forest Fire Laboratory has shown that a fuel bed of ponderosa pine needles can yield data of the type needed for experiments with fire retardants. This type of fuel bed was selected because it can be reproduced with reasonable accuracy, the needles are hygroscopic, and they are readily available.

Collecting and Mixing

Six hundred pounds of ponderosa pine needles were thoroughly mixed and cleaned of foreign material. After the cleaning and mixing, large wire baskets were filled with 10 pounds (dry weight) of needles.

Conditioning

The atmospheric conditions selected for the combustion laboratory and wind tunnel during the days of burning were temperatures of 90° to 95° F., and relative humidity of 15 to 20 percent. Moisture content of the fuels was brought to equilibrium with these atmospheric conditions. The fuel conditioning was accomplished in three steps:

1. The fuel was placed on the storage racks for several days; there its moisture content decreased to 1 to 2 percent above the equilibrium moisture content desired.
2. Enough fuel for 1 day's operation was placed in a forced-air drying oven at 110°-120° F. for 1 to 3 hours.
3. This fuel was then transferred immediately to one of two conditioning cabinets and held for 2 days at 95° to 100° F., and 12 to 14 percent relative humidity.^{4/}

Moisture content of the fuels in the storage rack, oven, and conditioning cabinets was sampled periodically for control purposes. At the time each fuel bed was built up, a separate small basket was filled with needles and placed with the fuel bed during its final conditioning period. This

^{4/} The conditioning cabinets operate on the saturated salt-solution principle; lithium chloride salt was used to hold the relative humidity to this level.

sample was taken from the fuel bed conditioning location within 5 minutes of ignition time.

The atmospheric conditions were nearly the same in the combustion laboratory as in the conditioning cabinets. Thus, there were no appreciable differences in the fuel moisture content between the two, as determined by the xylene distillation method. At the time of ignition, moisture content of the untreated sections of the fuel beds averaged 4.3 percent, plus or minus 0.5 percent.

Fuel Beds

Trays

The filled burning tray was designed to approximate as closely as possible a narrow section of an infinite fuel bed. Prior experiments showed that a bed width of 18 inches and a fuel depth of 3 inches would satisfy the major requirements. A length of 8 feet is necessary. The first 4 feet is needed to build up rate of spread and radiation from fire in untreated fuel to a steady state. The other 4 feet is used for measuring the rate of spread, radiant flux, and convection column temperatures of the chemically treated fuels. Sides of the trays used in the combustion laboratory (0 m.p.h. wind) were lined with strips of paper to prevent indrafts from the sides and more closely simulate an infinitely wide fuel bed. The paper was treated with monoammonium phosphate to prevent it from burning but to allow it to char and crumble after the fire passed. The sides of the trays used in the wind tunnel (3 m.p.h. wind) had permanent strips of asbestos sheets 3 inches high to prevent indrafts from the sides.

Fuel Bed Buildup

Six pounds of carefully arranged fuel is required for a tray 3 by 18 inches by 8 feet. The fuel was transferred from the conditioning cabinet directly into the combustion lab, which was circulating air at the predetermined temperature and humidity. Enough fuel for one tray was weighed and set aside in six 1-pound increments. Each pound was spread uniformly over a 4-foot length 1 inch thick by 18 inches wide. After the first layer was spread, one-third of the retardant was sprayed over the last 4 feet of the bed. Then the other two 1-inch layers were successively spread and sprayed. This fuel bed preparation and retardant application complied with the objectives of the test; that is, applying a known amount of retardant over a specified area of fuel and coating each piece of fuel.

After application was completed, stray needles sticking up above the general fuel bed level were cut off with scissors. Strings were then tied across the tray at 1-foot, 4-foot, and 7-foot marks and along the center line to facilitate accurate measurements during burning. The strings had previously been dipped in a monoammonium phosphate solution and dried to prevent them from carrying fire faster than the needles.

Identification

A card system was used to maintain control of the fuel as it moved through the various processes. Each fire, as represented by a burning tray, was identified as follows, using a 3-unit system:

1. Location of experiment. (C = Combustion lab; W = Wind tunnel)
2. Drying period. (1 = 1 hour; 3 = 3 hours)
3. Sequence number of the fire, either in the combustion lab or in the wind tunnel series. (3 = third fire; 11 = eleventh fire)

Examples: C-1-10 = Combustion lab, 1-hour drying time, tenth fire.

W-3- 7 = Wind tunnel, 3-hour drying time, seventh fire.

A



B



C



D



Figure 2.--Fuels: A, Mixing and weighing needles; B, Fuel storage rack; C, Drying oven; D, Conditioning cabinet.

A



B



C



D



Figure 3.--Fuels: A, Measuring out 1-pound increments; B, Building up a fuel bed; C, Hoisting tray into wind tunnel throat; D, Photographing burned fuel bed.

INSTRUMENTATION

The method of instrumentation was essentially the same in both the combustion laboratory and the wind tunnel. The placement and use of the instrumentation was designed to provide comparisons between untreated and treated fuels. Fire progress in the combustion laboratory was slow enough that rate of spread could be measured visually with sufficient accuracy. In the wind tunnel, however, rate of spread was so rapid that it had to be measured by thermocouples and oscillographs. Following is a summary of the instrumentation used in both burning areas (see also fig. 4):

Combustion Laboratory Instrumentation

<u>Parameter</u>	<u>Sensor</u>	<u>Readout</u>
Pressure drop across orifice	Pressure taps	ΔP controller
Convection column temperature	5 thermocouples in parallel	Recorder
Radiant energy	1 radiometer	Recorder
Dew point	Dew cell	Recorder
Air temperature	Thermistor	Recorder
Rate of spread	Stop watch	Clip board

Wind Tunnel Instrumentation

Rate of spread in untreated fuel	6 thermocouples	Oscillograph
Rate of spread in retardant-treated fuel	6 thermocouples	Oscillograph
Convection column temperature	5 thermocouples in parallel	Recorder
Radiant energy	1 radiometer	Recorder
Air velocity	Pitot static probe	Transducer and recorder
Dew point	Dew cell	Recorder
Air temperature	Thermistor	Recorder

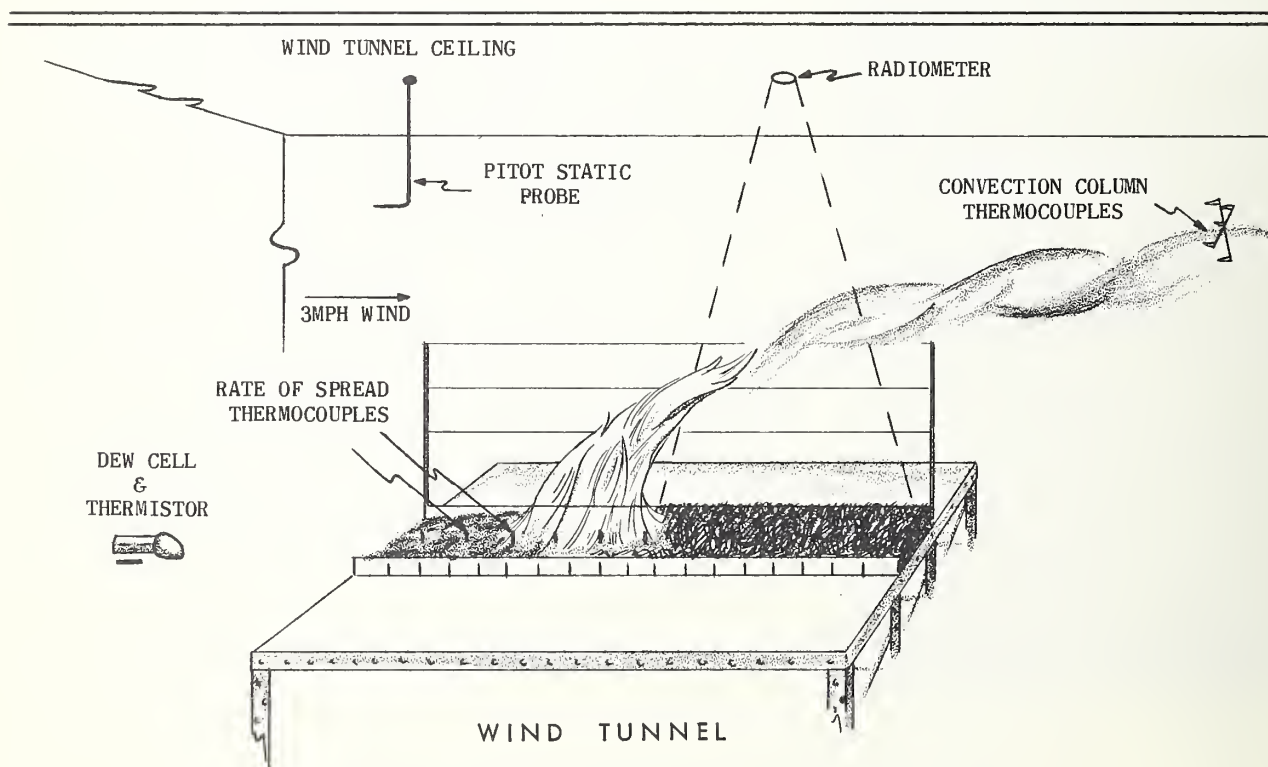
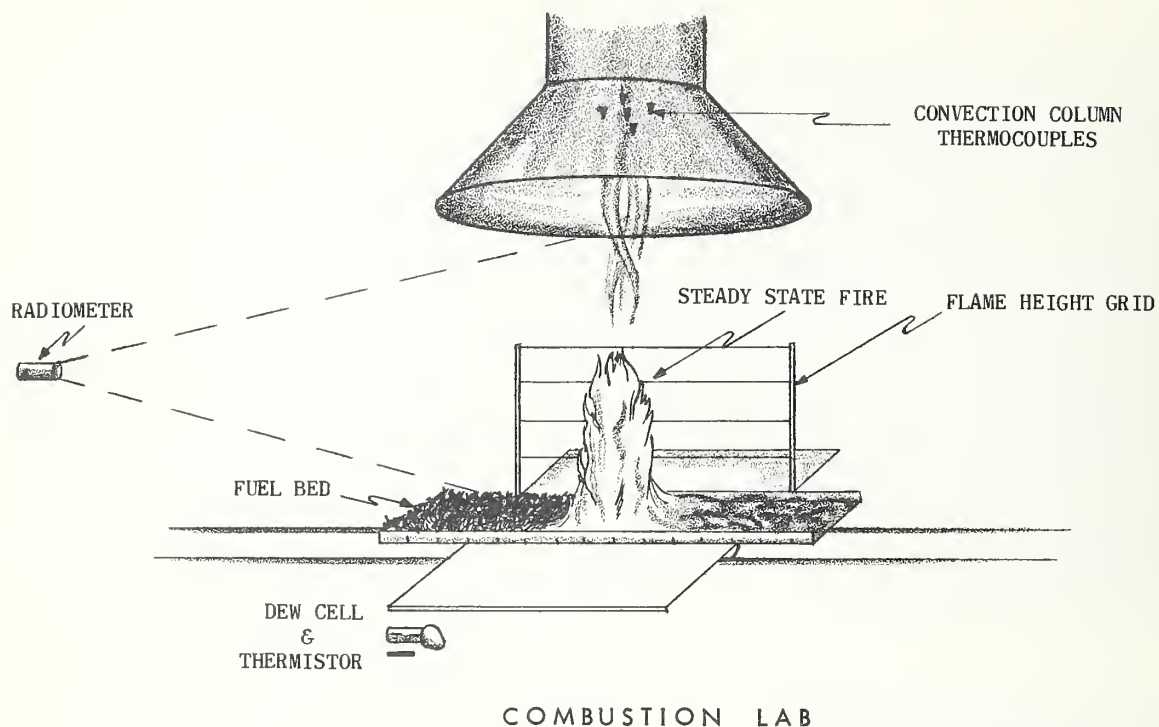


Figure 4.--Scheme of combustion lab and wind tunnel instrumentation.

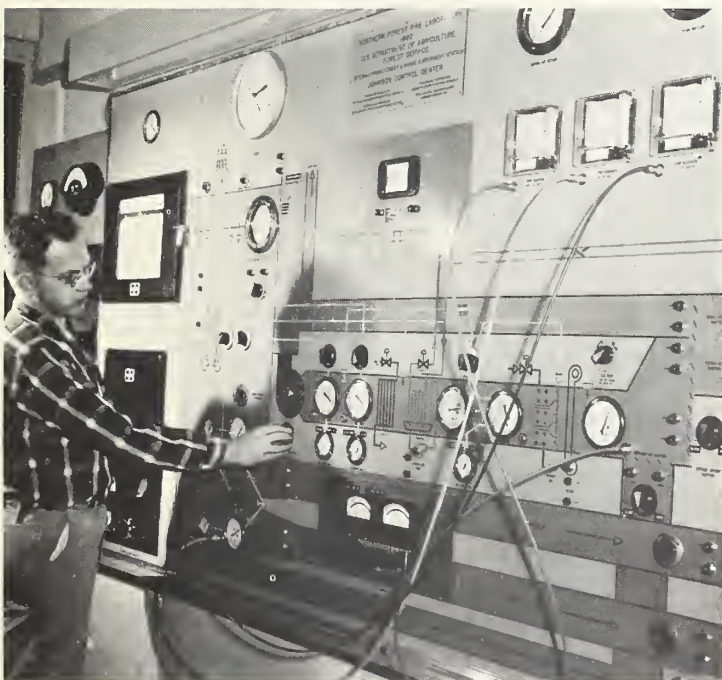
A



B



C



D



Figure 5.--Instrumentation: A, Calibration of wind tunnel air velocity; B, Installing thermocouples into burning tray in wind tunnel; C, Operating control panel; D, Monitoring recorders.

BURNING PROCEDURES

A sequence of burning was established that was compatible with several factors. Fuel bed buildup began by midmorning when proper atmospheric conditions were established in the combustion laboratory. Six fuel beds were burned each day, three with 1-hour drying times, and three with 3-hour drying times. Adequate time was allotted between fires to permit burning and removal of one tray, and placing and instrumenting the next. Adhering to the daily operation schedule shown in figure 6 permitted six fires to be burned each day.

Combustion Laboratory

Near the end of the drying period the fuel bed was transferred to a movable burning table. Five minutes before ignition, the fuel sample was removed to determine its moisture content, and all personnel not on the burning crew left the room. Upon signal from the control panel operator at ignition time, the fuel bed was ignited across its entire width by means of an 18-inch long alcohol tray, and simultaneously the rate-of-spread observer started his stop watch. The front of the fire was timed as it reached each one-half foot increment. As the fire advanced, the table operator moved the fuel bed so as to keep the flame centered under the exhaust hood and thereby maintain a constant distance from the radiometer. The elapsed-time observer timed the fastest rate of spread between the 1- and 4-foot marks and between the 4- and 7-foot marks. Flame height at the 5- and 7-foot marks was recorded by photographs of 1-second exposure time. The exhaust stack air velocity was held constant during the burn. An oral description of the fire was recorded on tape. After the fire, an overhead photograph recorded the fuel bed residue.

Wind Tunnel

Procedures in the wind tunnel were essentially the same as those in the combustion laboratory except that the fuel bed remained stationary. The increment rate of spread was measured by thermocouples, equally spaced in the fuel bed, rather than by a stop watch. The thermocouples were read out on two light-beam oscillographs. The wind speed was maintained as closely as possible to 3 m.p.h.

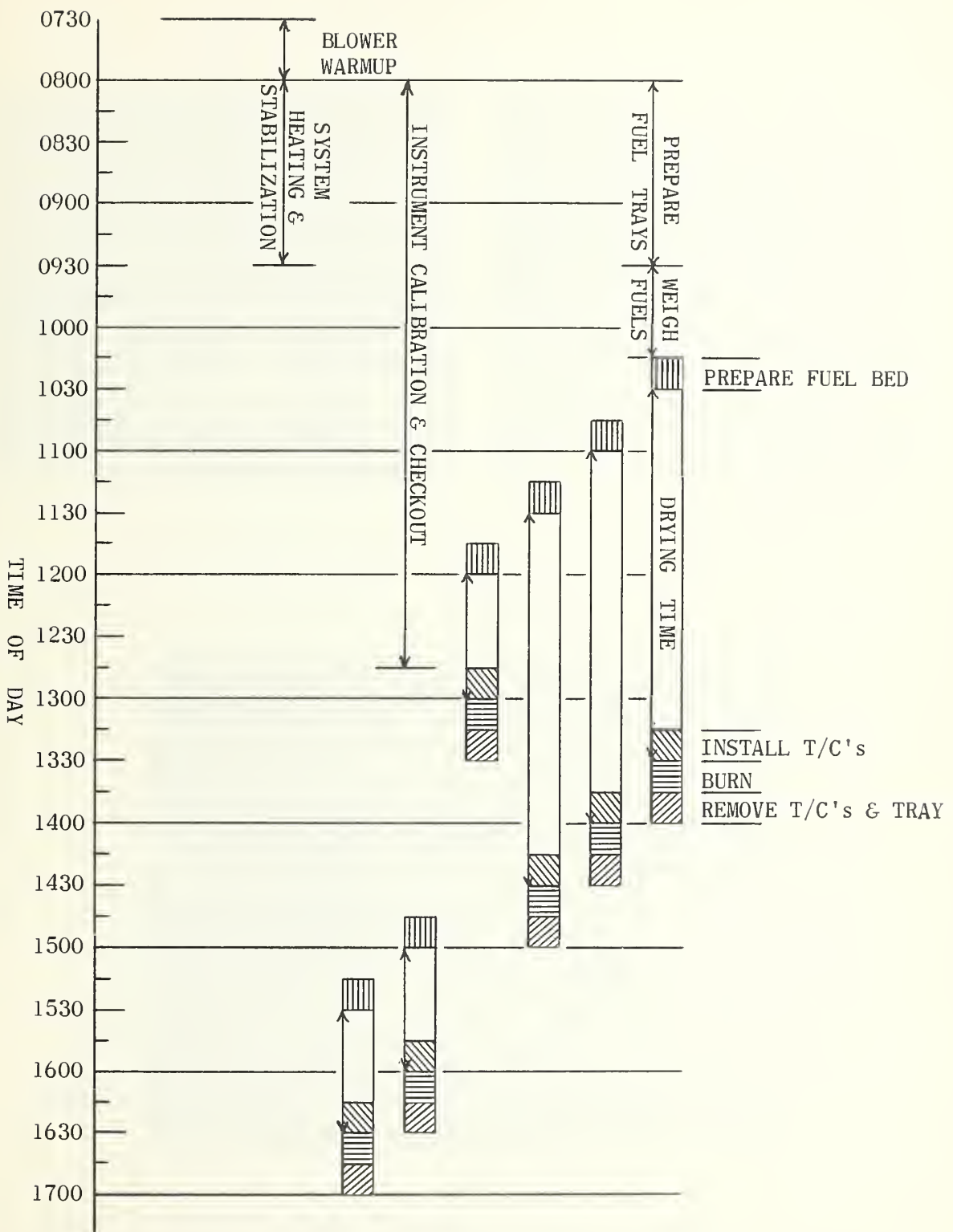


Figure 6.--Daily operating schedule.

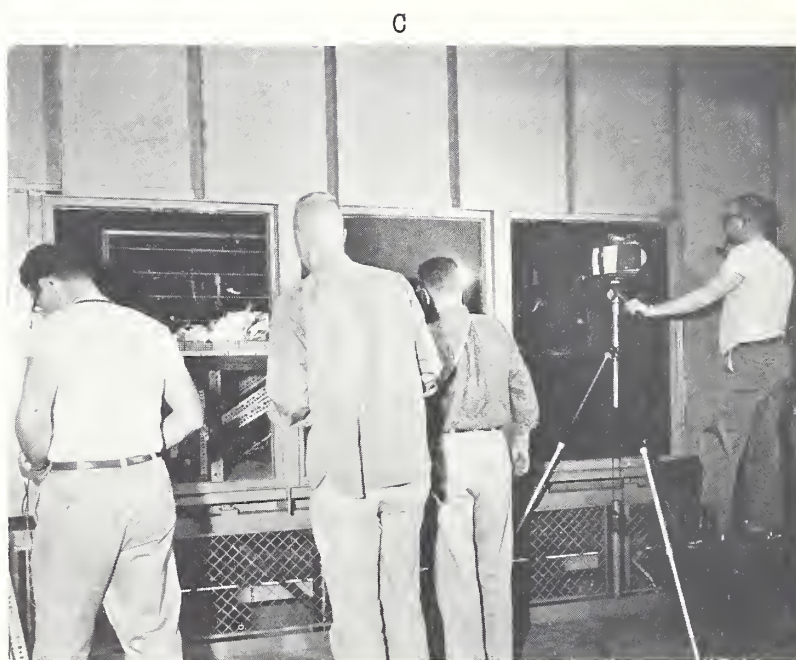
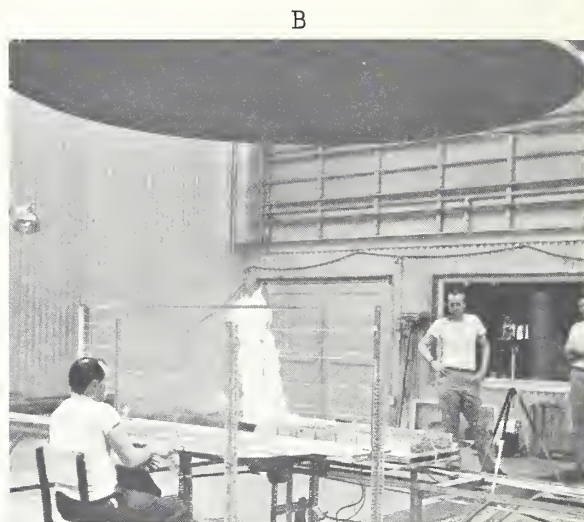
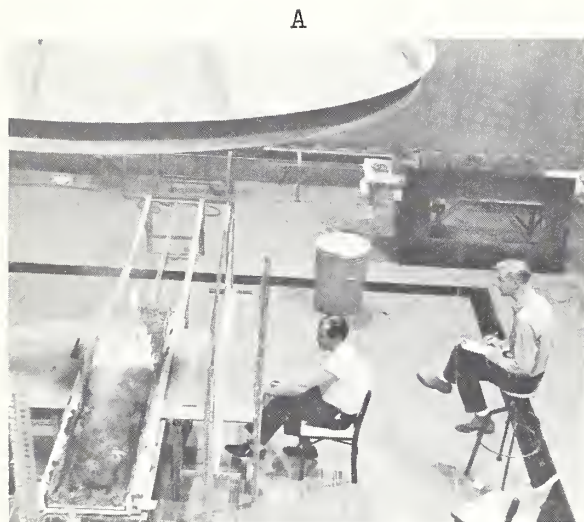


Figure 7.--Burning retardant test fires. A and B, Recording crew observing combustion laboratory fire; C, Recording crew observing wind tunnel fire.

AMBIENT CONDITIONS

Combustion research facilities at the Northern Forest Fire Laboratory can hold ambient conditions of air temperature, relative humidity, and wind speed within prescribed limits.

Limits imposed on the air temperature were 90°-95° F. The planned limits on relative humidity were 15 to 20 percent; however, the conditioning cabinets maintained relative humidity closer to 14 percent. Therefore, the lower limit on the relative humidity in the burning environment was reduced to 14 percent. The established wind speed of 3 m.p.h. at the fuel bed, or "ground level," corresponds to a measured speed of approximately 8 m.p.h. in the field, as measured by an anemometer 20 feet above the ground. The variation of these parameters is shown in the normal distribution curves of figure 8.

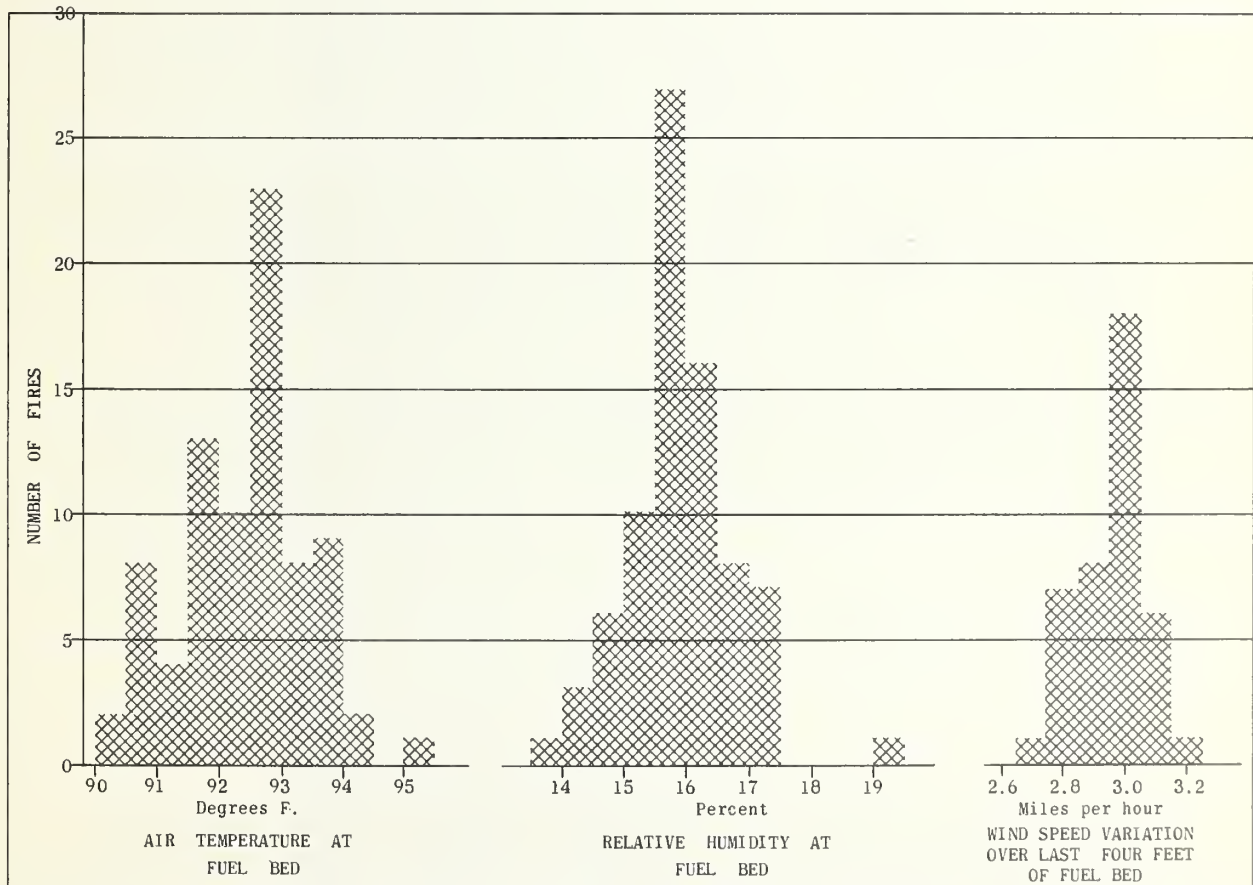


Figure 8.--Ambient condition distribution.

METHOD OF COMPARISON

Combustion Laboratory

Rate of spread, radiant energy flux, and convection column temperature from the 4-foot treated section of the fuel bed were compared to the same parameters as measured in the first (untreated) 4 feet of the same fuel bed.

Wind Tunnel

Each parameter was compared to the average value of the same parameter as measured in the last 4 feet of three untreated fuel beds.

Photographic Comparison

Photographic record of the flame characteristics at the 5-foot and 7-foot marks indicated in general the flame height, depth, and vigor. A photograph of the burned-out fuel bed from directly overhead illustrated again the intensity of the fire and the degree of total fuel consumption. The photographs in figures 9 to 12 compare for each chemical, drying time, and wind speed group, the characteristics of a representative fire in a treated and an untreated fuel bed. In the postburn views, the left half of the fuel bed was untreated, while the right half was treated with the designated chemical. A splotchy or light color indicates ash and thus rather complete consumption. Needles in sections showing a black or very dark color still held their shape and body, indicating arrested combustion. In the wind tunnel tests, the bottom layer of the darkest sections often contained patches or entire layers of completely unburned needles.

RESULTS

The data spread in each pair of fires used for computing the average rate-of-spread reduction and the average radiant energy flux reduction can best be described by referring to figure 13. The better the retardant, the farther the point is from zero. The better the repetition, the closer together is each pair of symbols. If the first two fires for each retardant, after the same drying time and wind speed, did not agree within approximately 10 percent on all three parameters (rate-of-spread reduction, radiant energy flux reduction, and convection column temperature reduction), burning was repeated until two fires gave similar results. For most tests, two fires were sufficient; for a few others, three or four fires were necessary.^{5/}

^{5/} After the burning program had been terminated, closer observation of the data revealed a 24-percent variation in the rate of spread of pectin-DAP after 3 hours' drying time at 3 m.p.h. This is not believed to be serious, however, since the other comparisons made on pectin-DAP are consistent and define its relative standing with the other retardants.

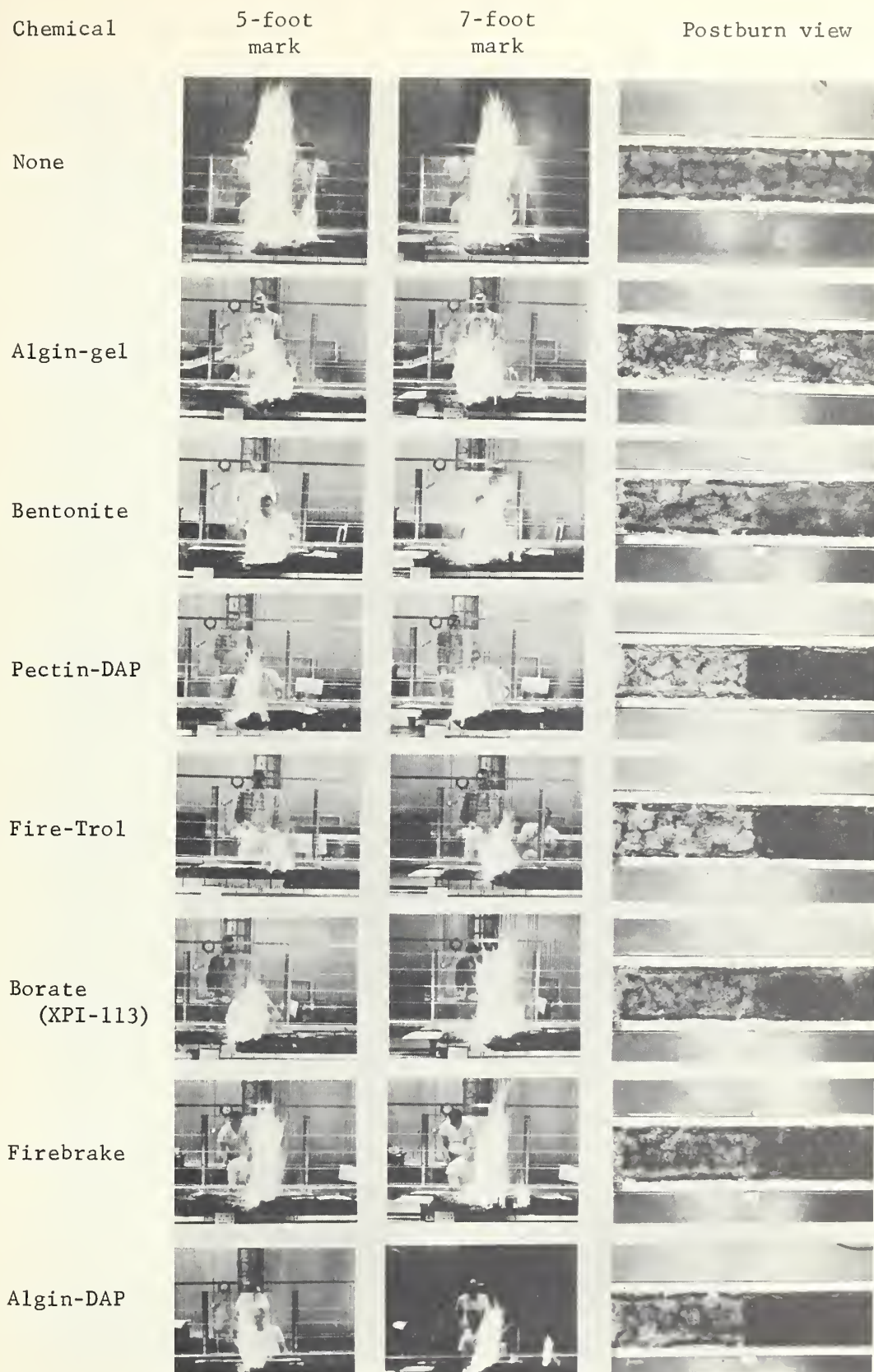


Figure 9.--Fire characteristics, under no-wind and 1-hour drying time conditions.

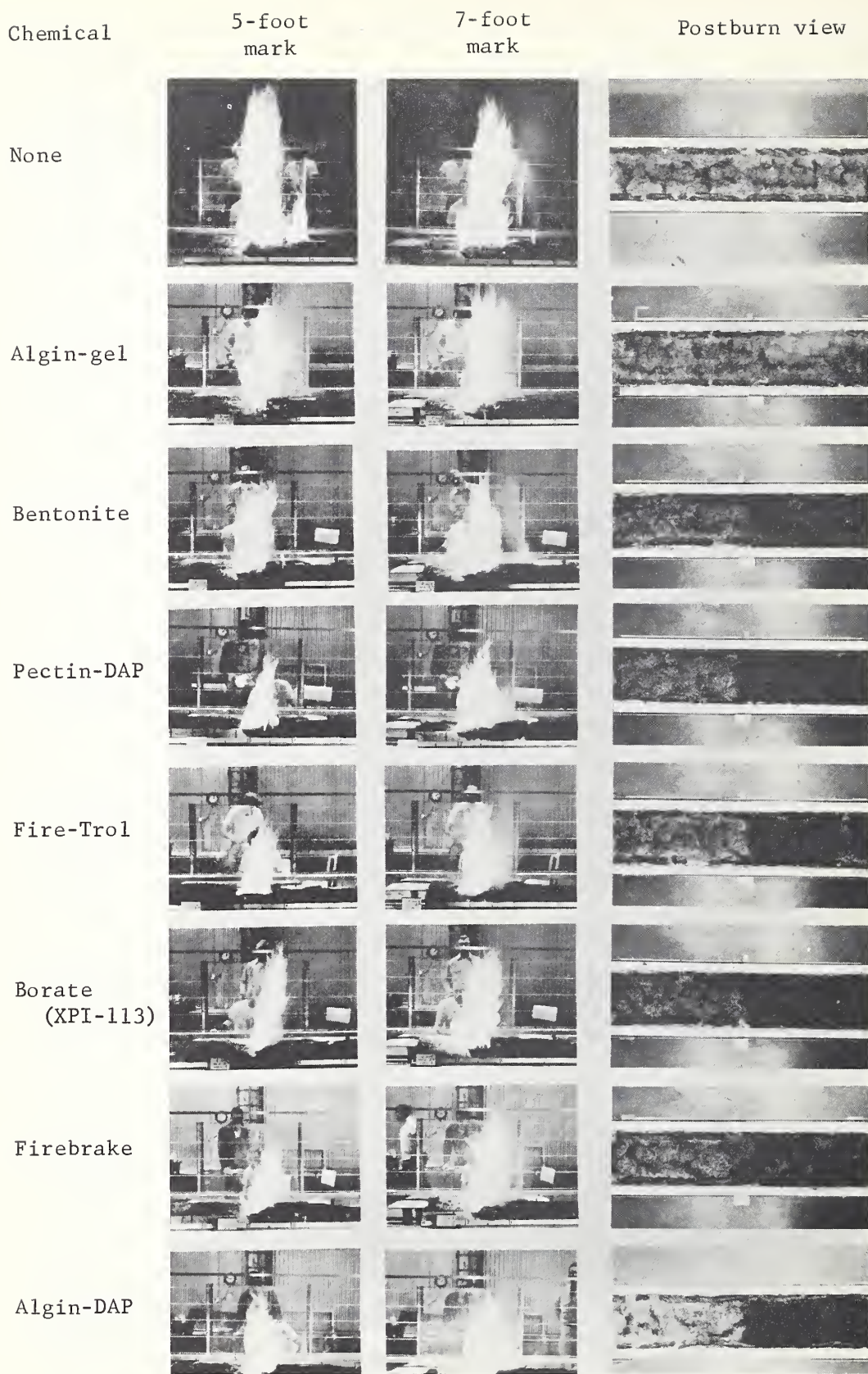


Figure 10.--Fire characteristics, under no-wind and 3-hour drying time conditions.

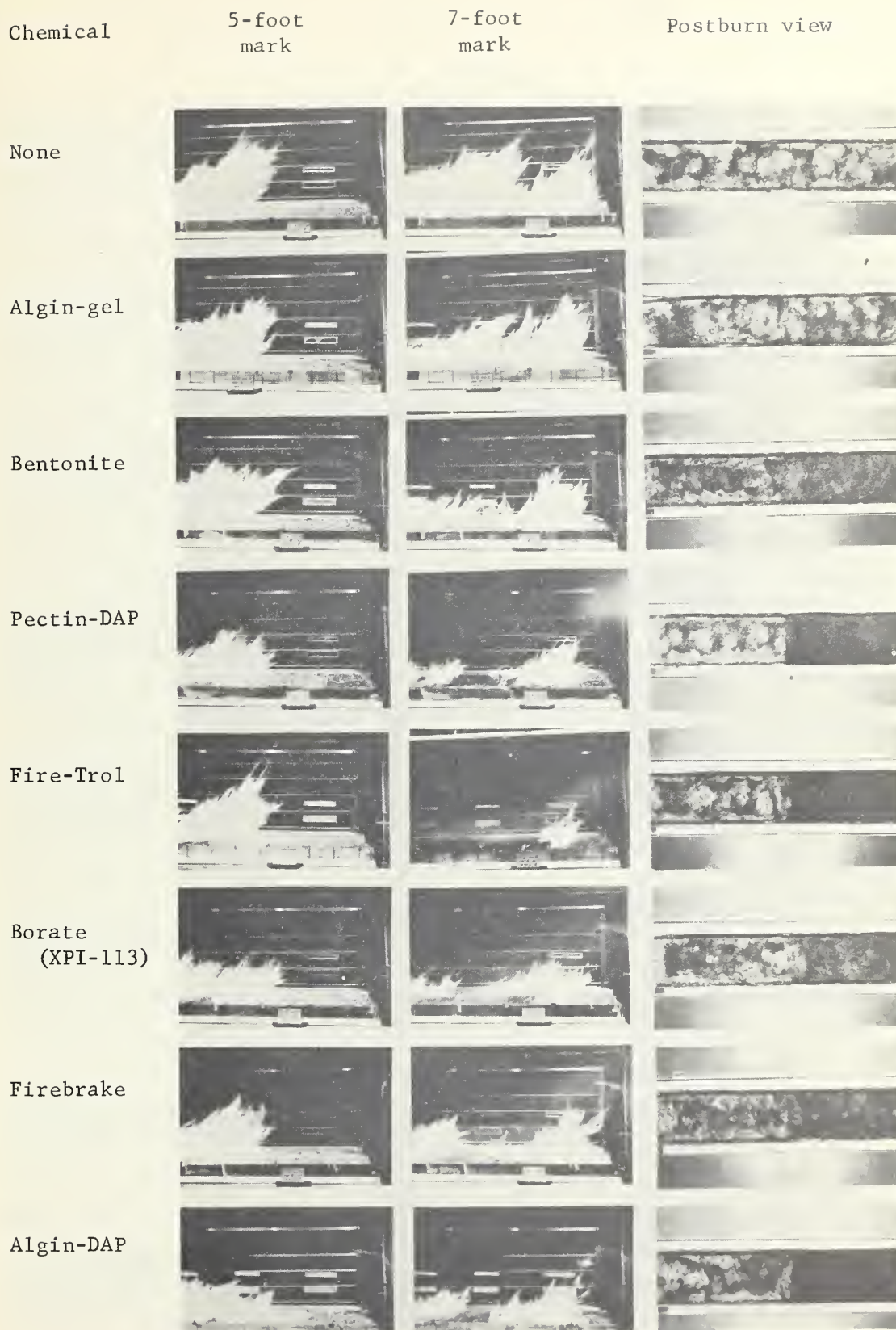


Figure 11.--Fire characteristics, under 3 m.p.h. of wind and 1-hour drying time conditions.

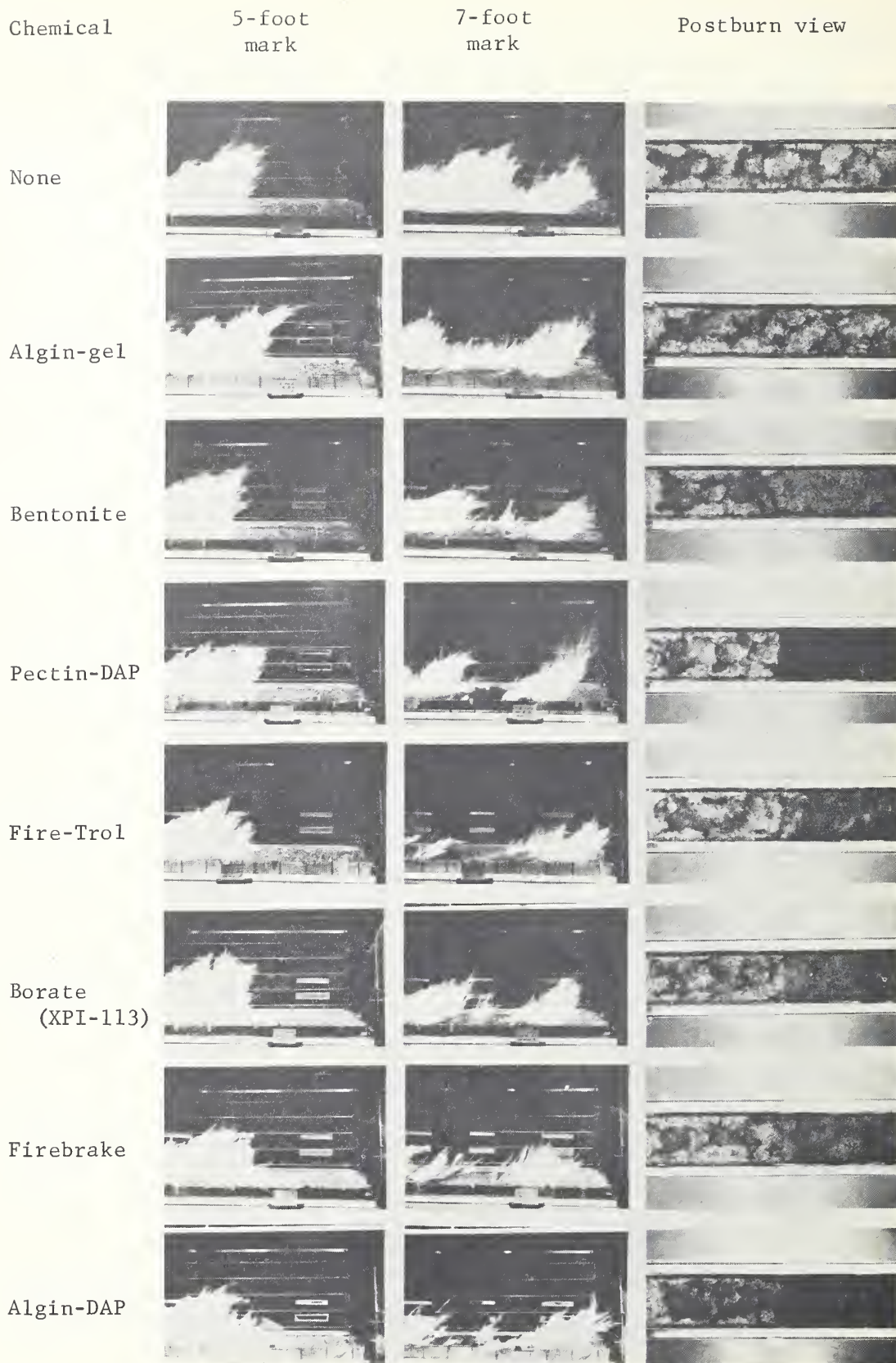
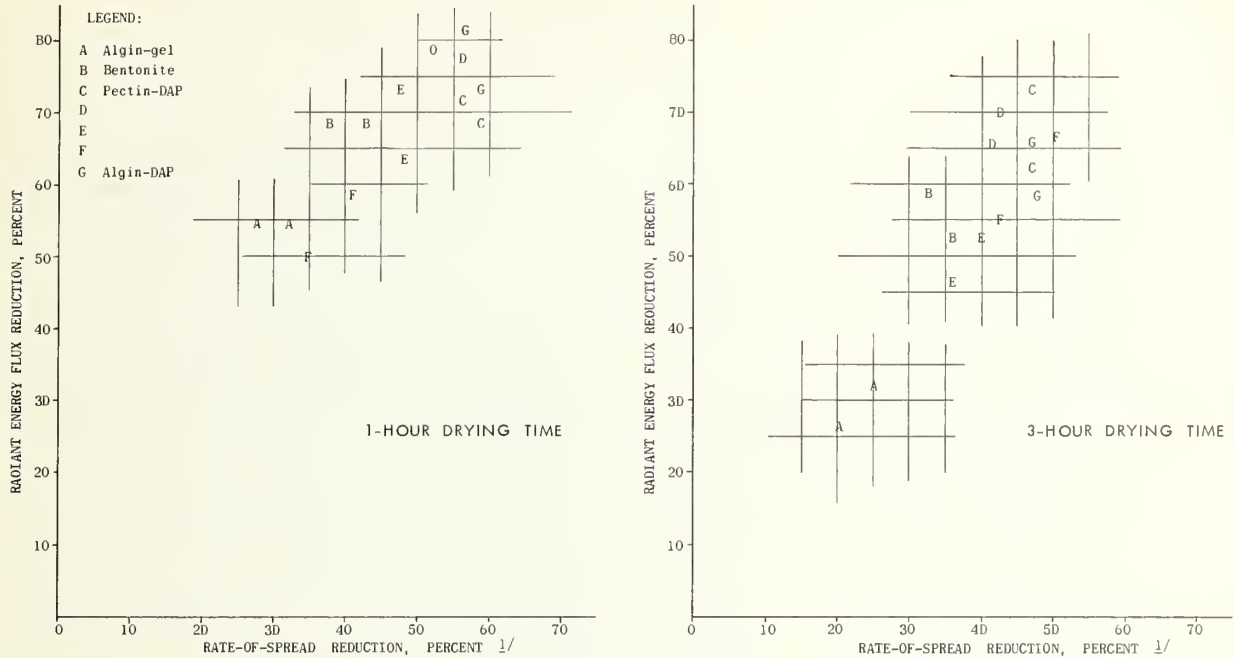
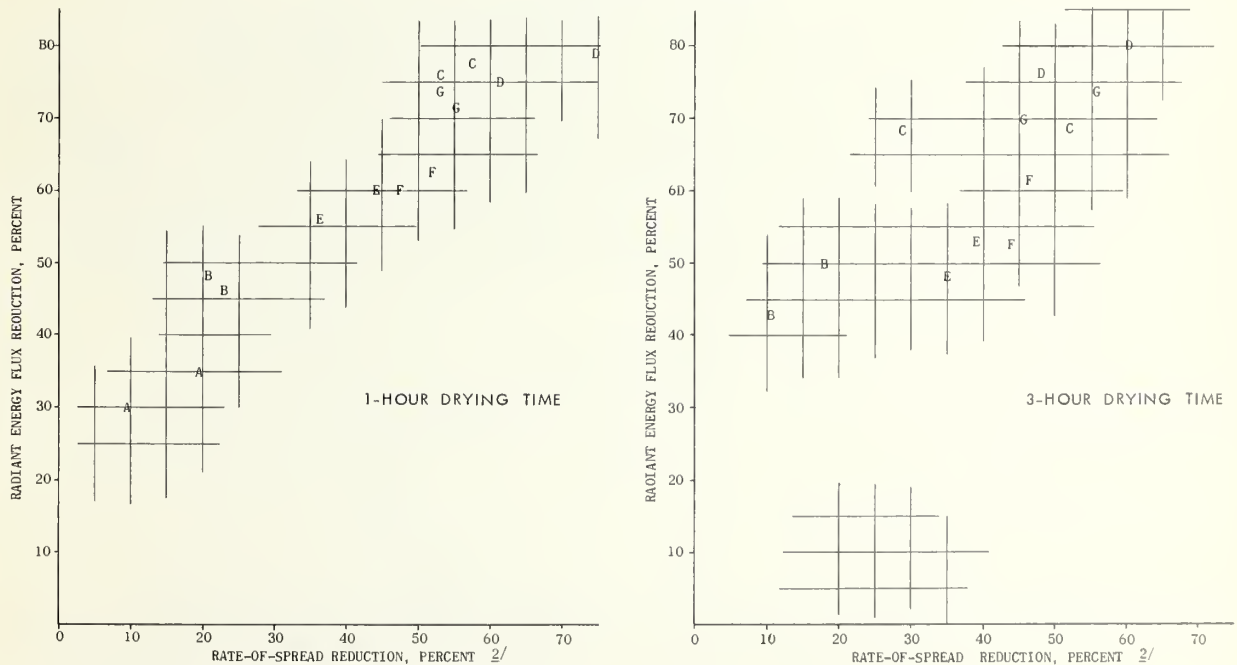


Figure 12.--Fire characteristics, under 3 m.p.h. of wind and 3-hour drying time conditions.

NO WIND



3 MILES-PER-HOUR WIND



1/ Reduction based on untreated first four feet of each fuel bed.

2/ Reduction based on average values in the last four feet of three untreated fuel beds.

Figure 13.--Data spread in each pair of fires used for computing the average rate-of-spread reduction and average radiant energy flux reduction.

The differences between effectiveness shown by plotting these data seemed sufficiently obvious for selection of retardant chemicals for field testing. Hence, the data were not subjected to any rigorous type of statistical analysis.

Rate of Spread

Relative effectiveness of the retardants in reducing rate of spread is shown in figure 14. Under no-wind conditions, algin-DAP and pectin-DAP effected the best reductions after 3 hours' drying, along with Firebrake. In the presence of wind, Fire-Trol gave the best results after both 1 hour and 3 hours' drying. The contrast between Firebrake and bentonite should be noted. After 1 hour with no wind, bentonite was slightly more effective than Firebrake, but after drying for either 3 hours with no wind or 1 hour in the presence of wind, Firebrake was considerably more effective than bentonite. Bentonite was least effective after 3 hours of drying in the presence of wind. Borate XPI-113 usually ranked between bentonite and Firebrake. As a retardant, algin-gel did not perform as effectively in these tests as it had in some preliminary field experiments.

Radiant Energy Flux

Fire-Trol and the diammonium phosphates caused the greatest reduction of radiant energy in all burns. Bentonite was more effective after 1 hour drying time in the absence of wind, and Firebrake increased its effectiveness with a certain amount of drying. Borate XPI-113 usually ranked between them, and algin-gel was the least effective retardant (figure 15).

Convection Column Temperature

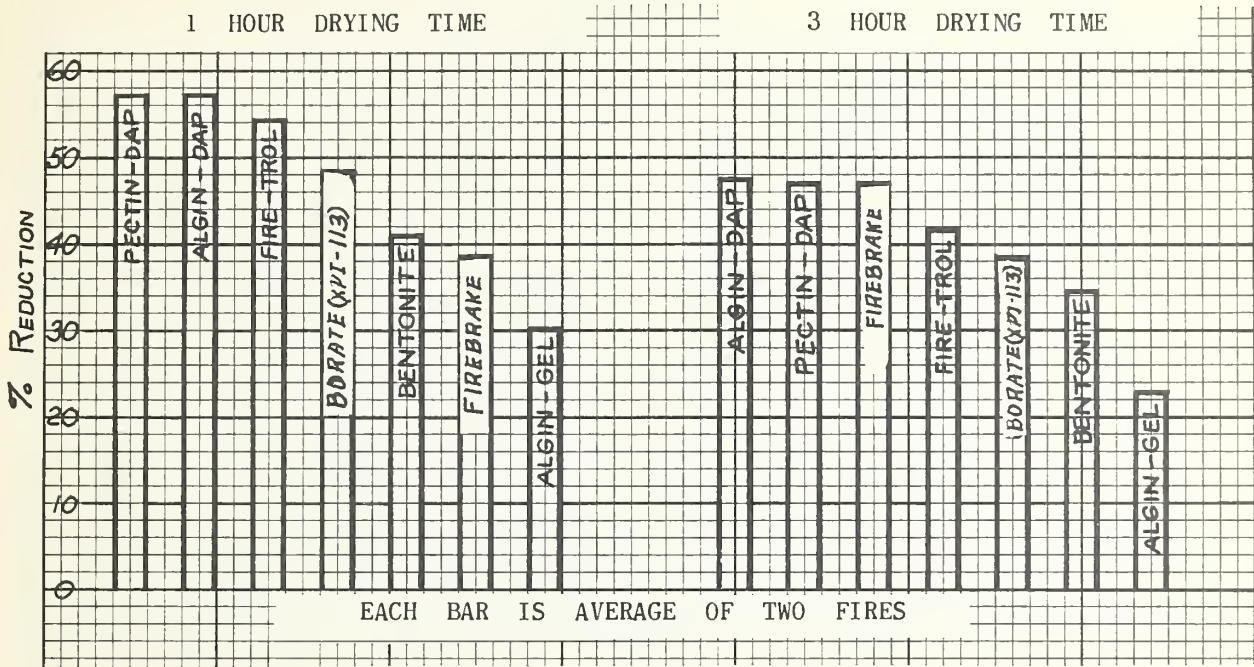
This parameter is probably less significant than rate-of-spread reduction and radiant energy flux reduction; however, the same general relation between the chemicals was maintained by this means of evaluation (figure 16).

Significance

It is necessary to remember that these results indicate only the relative effectiveness of the chemicals in reducing the intensity of fires burned under consistent conditions. No other qualities of the retardants were considered in this phase of the evaluation system.

A fire retardant chemical, successful from laboratory and field-testing standpoints, may still not be ready for operational testing or general field use. Chemicals containing ammonium phosphate and ammonium sulphate are corrosive to many metals. Solution to this problem may be through addition of corrosion inhibitors, protection of exposed aircraft parts, development of rigid inspection and maintenance guidelines, or some combination of these.

NO WIND



3 MILES PER HOUR WIND

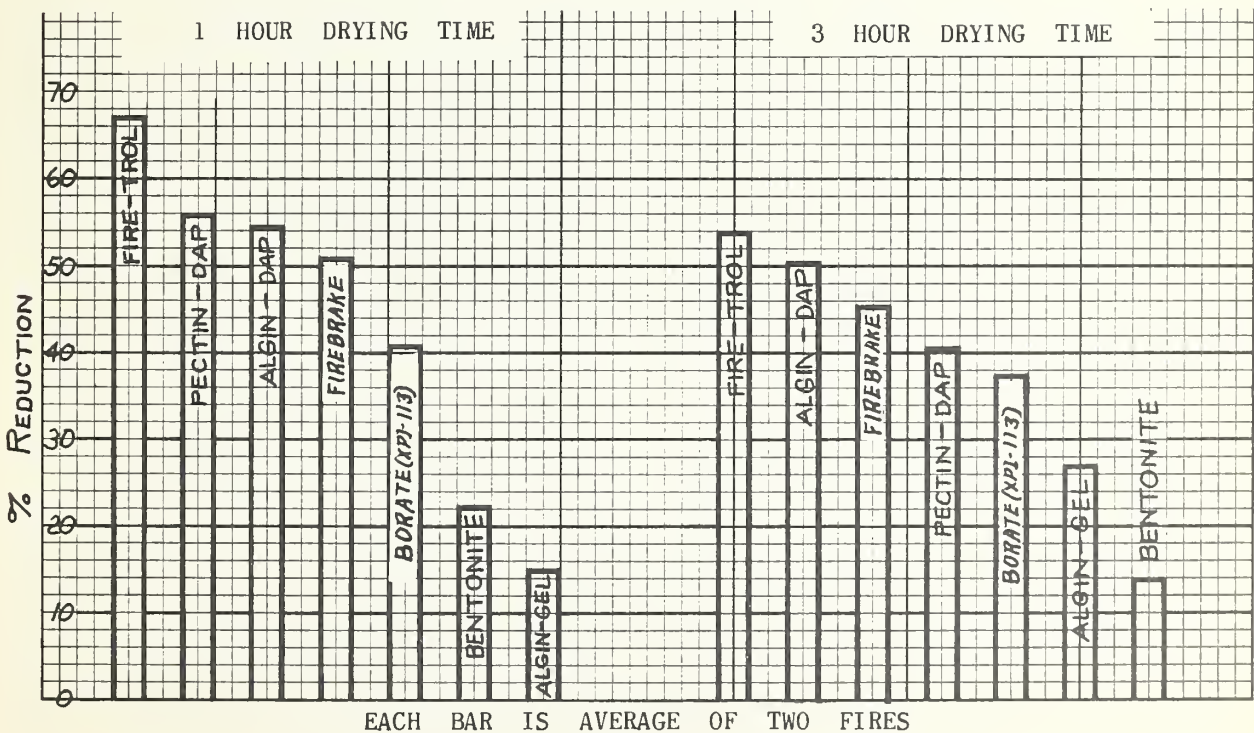


Figure 14.--Percent reduction in rate of spread of flame front.

NO WIND

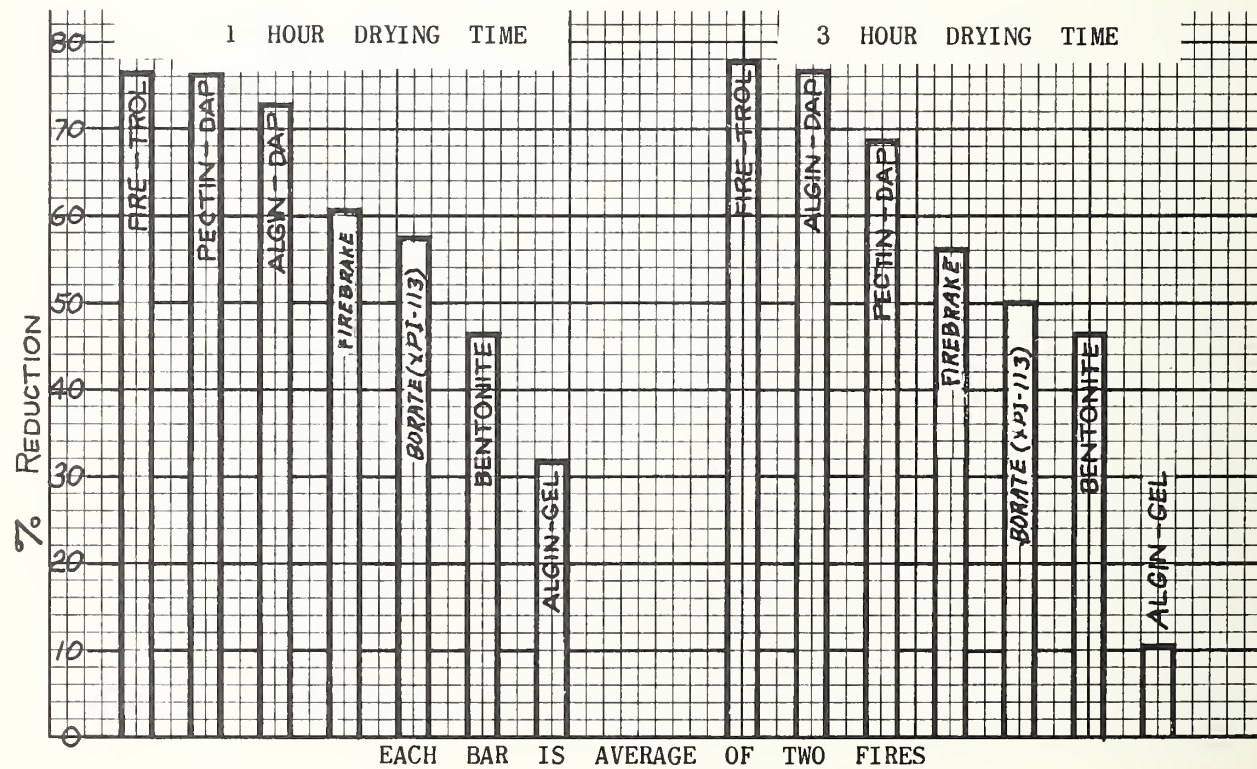
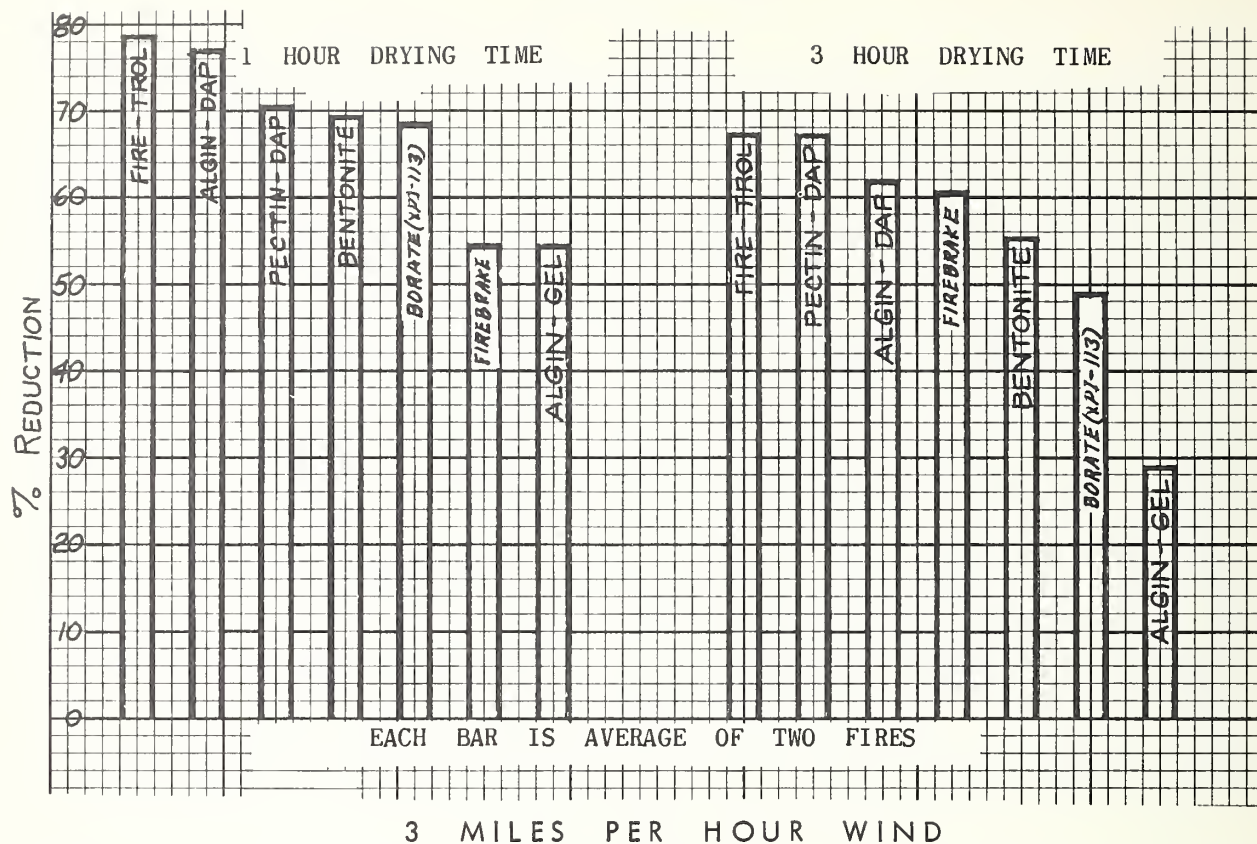
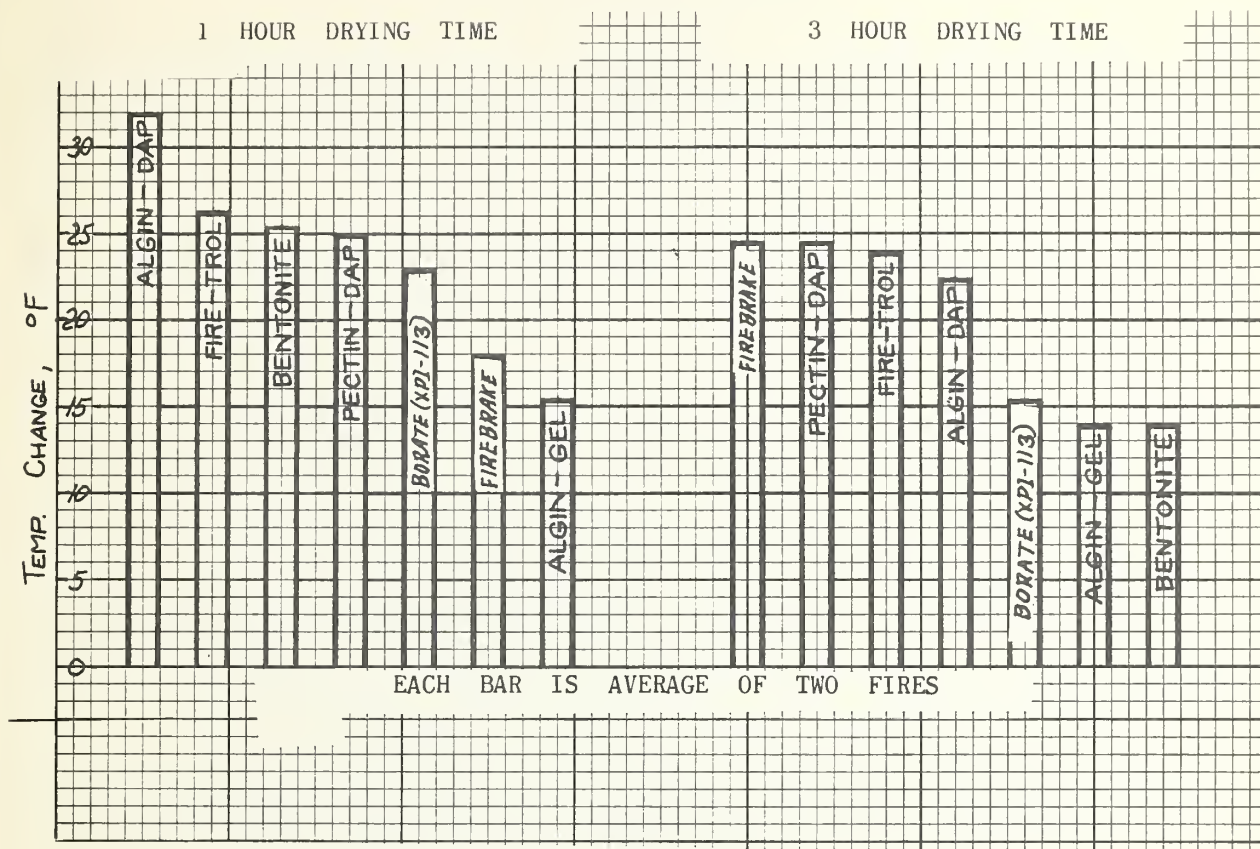


Figure 15.--Percent reduction in radiant energy flux.

NO WIND



3 MILES PER HOUR WIND

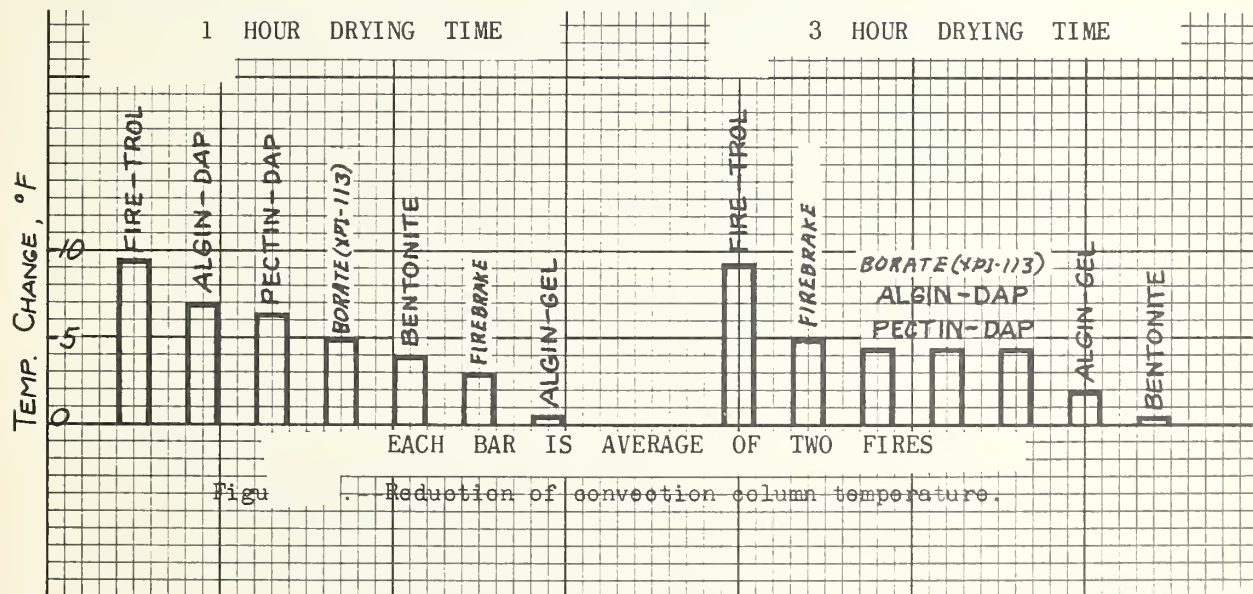


Fig. 1. Reduction of convection column temperature.

WHERE DO WE GO FROM HERE?

Field-testing of the most promising chemicals is the next logical step to follow this laboratory evaluation. The field tests will be followed by operational tests and evaluations, which in turn will result in the development of application guides, as outlined in phases 5 through 8 under the FIRE RETARDANT EVALUATION SYSTEM section above (pp. 3-4).

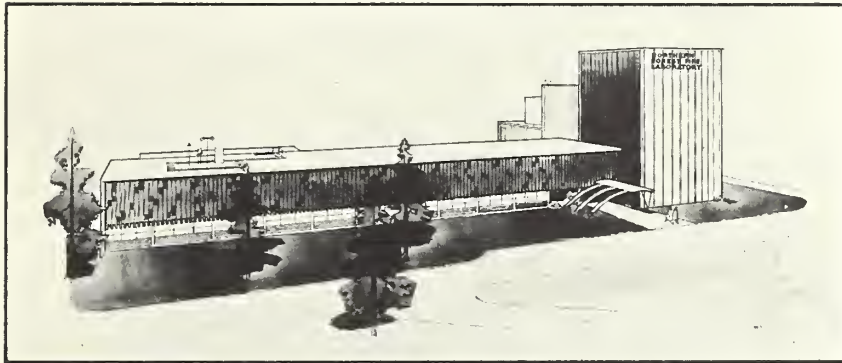
Keeping performance requirements realistic and up to date is a continuing task. Also, the screening and laboratory testing phases of this system must continue to be active. A specific program of field evaluation is described in the following paragraphs.

Air drops will be made over prepared plots of standing brush. The retardant materials will be allowed to dry on the vegetation for a specified length of time following the drop. Later the brush plots will be ignited and the fire allowed to spread into the retardant-treated portion of the plot. The plan is to burn each plot under similar weather and fuel conditions. The length of each retardant line that successfully stops the fire will be measured. Each experimental burn will be photographed to record results given by each chemical applied. This series of field tests should yield quantitative data that will permit comparisons of retardant effectiveness under field conditions.

Plans are being developed by CALAIRCO for further testing of the material that shows the greatest promise in these field tests by using it at six or more air tanker facilities in California and possibly elsewhere in the West. Besides using the new materials, each base will continue to use the already field-proved bentonite or Firebrake. Alternating drops of new and old material are planned so that a direct fire-line comparison can be measured. Information on drop effectiveness will be obtained from a standard reporting system.

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The research reported in this publication was performed at the Northern Forest Fire Laboratory, Missoula, Montana, a unit of the Intermountain Forest and Range Experiment Station.

